Nb CAVITY EP SUMMARY AS OF DECEMBER 2005

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Abstract

This document presents an outcome of the discussions at the TTC meeting at Frascati on 5-7 December 2005, which was a continuation from the SMTF meeting held at FNAL on 5-7 October 2005. Our goal was to identify the cause of the results spread of EPed 9-cell Nb cavities that have been tested mostly at DESY. While the spread might not have been caused only by the EP itself, the fact that the spread is larger than BCPed cavities may suggest that the EP process or EP-related contamination due to such as sulfur may be the cause of the problem. After the discussions on EP parameters and current issues, we suggest that the following be carried out with R&D efforts as highest priority items: 1) further study how important it is to control HF content and what is an appropriate range, 2) establish the best way to eliminate sulfur, a reaction product while EP and is insoluble to water, 3) study how hydrogen gets into the cavity during EP and find a way to eliminate it, and 4) study the effectiveness of mechanical polishing before EP such as CBP at KEK on the reproducibility of the results and for the reduction of the amount of EP. In addition, we encourage other ongoing R&Ds including EP simulation for better understanding of EP process and vertical EP studies as supporting elements and for future cost reduction. Working group was led by P. Kneisel, K. Saito and D. Reschke at the TTC meeting and all the presentations can be found at http://www.lnf.infn.it/conference/ilc05/programme.html. The SMTF meeting at FNAL was led by T. Tajima and C. Boffo and the presented files are shown at http://ilc-dms.fnal.gov/Workgroups/SMTF/Collaboration Meetings/SMTF Collaboration Meeting Oct 5,6,7 2005/.

ACRONYMS

ANL	Argonne National Laboratory
BCP	Buffered Chemical Polishing
CARE	Coordinated Accelerator Research in Europe
CBP	Centrifugal Barrel Polishing
CEA	Atomic Energy Commission, France.
DESY	Deutsch Electron Synchrotron Laboratory
EP	Electro-Polishing
GMR	Giant Magneto Resistance 2nd order gradiometer
HPR	High Pressure (water) Rinsing
HRC-EP	Horizontally Rotated Continuous Electro Polishing developed at KEK
INFN	National Institute of Nuclear Physics, Italy
INFN/LNL	INFN Legnaro
INFN/Mi	INFN Milano
KEK	High Energy Accelerator Research Organization, Japan.
QA	Quality Assurance
SMTF	Superconducting Module Test Facility
TTC	TESLA Technology Collaboration
WG	Working Group

INTRODUCTION

The HRC-EP that was developed by KEK and Nomura Plating company [1, 2] has been adopted by DESY and JLAB. DESY has carried out 90 EP processes since it started in 2004 for a total processing time of 199 hours [3]. JLAB has processed a few 700-MHz, 805-MHz and 1.5-GHz multi-cell cavities with their system and has identified some issues to improve their system, although due to funding shortage they have not been able to do a lot on EP in the recent years.

The major goal of this WG was to discuss EP parameters and the reason why the spread of EPed 9-cell cavities is so large, i.e., $20<E_{acc}(MV/m)<35$ as shown in Fig. 1 based on mostly DESY data [3]. We discussed important parameters, what are the issues that need further R&D for clarification and solution.

There were some presentations on single/large grain cavities and seamless cavities, but they were excluded from this document to focus on EP.

BRIEF HISTORY OF EP

At the TTC meeting, Peter Kneisel gave a comprehensive review of the history of EP that has been adopted for treating accelerator structures [4]. The following shows the brief history from his talk and some supplemental information from Ken Shepard of ANL.

- In 1971, H. Diepers and coworkers of Siemens AG developed a new method of electropolishing Nb within a government funded collaboration agreement with the Kernforschungszentrum Karlsruhe (KfK) [5].
- The process was subsequently used for the surface treatment of cavities (RF separator, helix, R&D) at KfK.
- Beginning in 1971 the (Siemens) process was used at ANL for helix structures and in 1975 for split-ring structures [6].
- In ~1975, it was "exported" to HEPL [7], Cornell and KEK.
- In ~1980, K. Saito and Nomura Plating Company modified and developed the HRC-EP method for 508 MHz 5-cell TRISTAN cavities [1].

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The EP related figures in Refs. [1] and [2] are shown in Appendix A. Appendix B shows chemical reactions that can occur during EP.

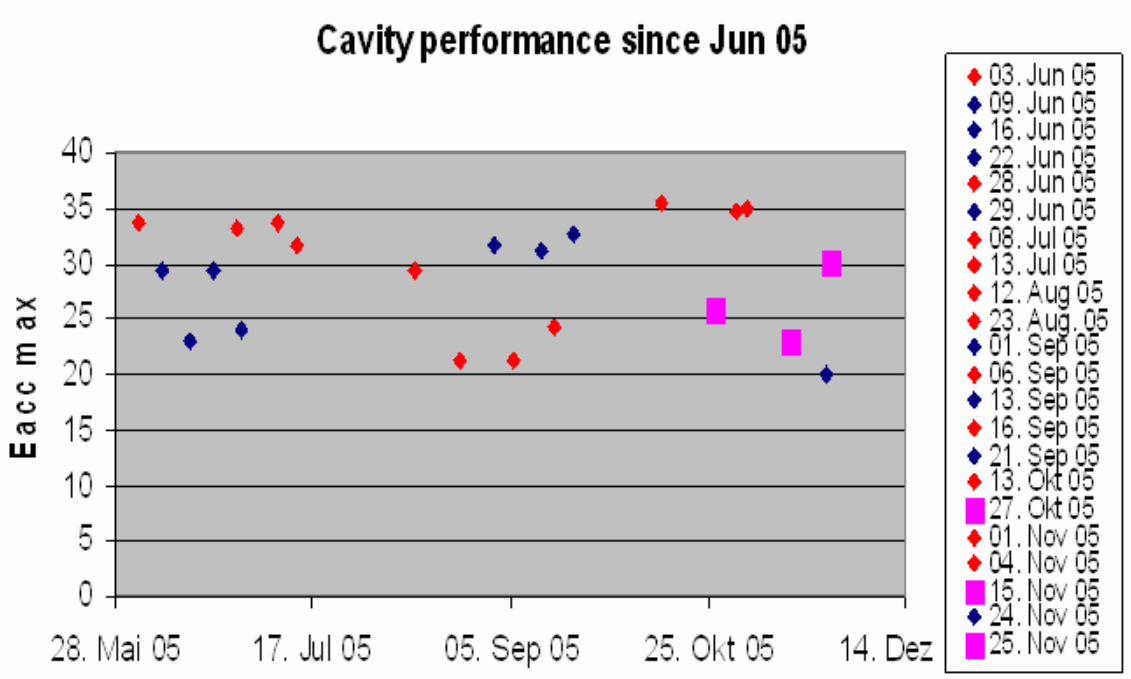

Figure 1: Performance of EPed DESY 9-cell cavities since June 2005 [3]. Red diamonds show the results after 120 °C baking and the purple squares show those after fast cool down of the cavities that have Q disease.

INSTITUTES THAT HAVE EP CAPABILITY

Table 1 shows a list of institutions and their experience. Presently, DESY and KEK/Nomura have the full capability of electropolishing 9-cell cavities. JLAB has a facility that is large enough to accommodate a 9-cell cavity, but they have no experience so far. Appendix C shows the EP facilities at DESY, JLAB and KEK/Nomura. Appendix D shows small facilities for shorter cavities or for sample tests.

Table 1: List of institutions that have EP capabilities.

Institution	Facility	Experience	Ref.
ANL	for low-β structures	Since 1972	[6,8]
CERN	1-cell	Since 1999	[9,10]
Cornell	Vertical EP	Since 1999	[11,12]
DESY	HRC-EP	Since 2003	[13-17]
FNAL	Small tests	Since 2004	[18]
JLAB	HRC-EP	Since 2003	[19]
INFN/LNL	R&D on GMR and Automated EP	Since 2004	[20]
KEK	HRC-EP	Since 1980	[1,2]
Saclay	Small tests & mono-cell	Since 2004	[21,22]

IMPORTANT PARAMETERS

The parameters in Table 2 have been agreed to be important and most of them have been the same as or scaled from the data described in K. Saito's paper [1]. These ranges were mostly determined by sample roughness and brightness measurements.

Table 2: Important EP Parameters for 1.3 GHz elliptical cavities.

Parameter	Range	Notes
Current density	30-100 mA/cm^2	High end still has room for exploration
Voltage	8 – 16 V	Depending on the current density and HF content
Bath (solution) temperature	25 – 35 °C	
HF concentration	60 – 90 cc/L	Needs further study
Rotational speed	0<rpm<10	See Figs. A.15 and A.16
Acid flow rate	1 – 2 l/min	See Fig. A.17

Another important fact is that the viscous layer on the anode (Nb) surface needs to be preserved for EP to occur, i.e., too much turbulence that breaks this layer will lead to an unsuccessful EP.

MATERIALS

Some materials have been found incompatible with the EP acid. They are:

- Viton: There are various types of Viton and there might be compatible Viton.
- PVDF: DESY has used this for the part that needs welding since this is the only material that seemed compatible and weldable.

Teflon® or polytetrafluoroethylene (PTFE) is the ideal material to be used wherever possible.

Other issues related to materials that need to be reminded are:

- The cathode needs to be made of a pure aluminum (1100) to avoid corrosion.
- The tubes for heat exchanger could be pure aluminum, but the EP acids need to be mixed elsewhere before adding to the heat exchanger to avoid corrosion of Al tubes. (ANL uses Al tubes.)

NEW RESULTS AND OTHER ISSUES

Recent studies with 9 cm^2 samples at Saclay supported by EU CARE program have shown the following results [22].

- After 5-7 g/L Nb has been reached, the surface state starts to degrade. This, however, seems to be at least partially due to a decrease of HF content and could be different for actual cavities.
- The increase in HF content increases polishing rate, Nb solubility and acid solution lifetime, and it decreases the production of sulfur. The drawbacks, however, are corrosion of Al cathode, safety issues and difficulty in temperature control due to high removal rate.

DESY has found the following issues.

- The acid mixture delivered from a company was not the right mixture in the past, suggesting that the QA of delivered acid is an important issue.
- Some EPed cavities show Q disease, but not all the cavities, which may suggest that there were some difference(s) during EP process, although they could not find any difference in recorded operating parameters.
- There seems to be difference in removal rates in different cells according to the field flatness measurements. KEK has not had this problem, although they have checked with only one 9-cell cavity so far. This could have been an effect of handling after the EP [23].

Recent studies at ANL, using both low-beta cavities and samples, indicate [24]:

- No substantial polishing-rate dependence on the anode connection point (opening the possibility of polishing a cavity with the titanium He vessel on).
- No significant polishing-rate dependence due to the detailed cathode shape.

POSSIBLE CAUSES OF EPeD CAVITIES RESULTS SPREAD

The question whether it is due to EP itself or to the subsequent process remains to be answered. However, assuming that the subsequent process has been the same quality as BCP cavities, the following are the possible causes that have been discussed so far.

- The EP parameters have not always been controlled to be within the range shown in Table 2.
- Removal of chemical contaminations such as sulfur was not always complete.
- The quality of the delivered acid mixture was not always the same.
- The initial cavity surfaces before EP were not the same quality among different cavities.

R&D ITEMS

Table 3 shows the currently ongoing R&D efforts at various laboratories. Through the discussions at Frascati and FNAL, we have identified the areas where we need to intensify R&D in a timely manner. They are:

- Effect of controlling HF content and determine an appropriate range for proper EP.
- Effect of eliminating sulfur with either oxipolishing, H_2O_2 rinse or methanol rinse, etc.
- Effect of pre-polishing such as CBP on the results spread. Currently, KEK is the only place where an advanced CBP facility is available and hopefully they can do this R&D expeditiously in collaboration with other labs.
- How hydrogen gets into the cavity during EP and how to eliminate it.
- Effect of cathode configuration, current leads positions, local temperature, solution speed, etc. on the removal rate.

Other engineering issues are how to:

- Monitor and control the local temperature so that the cavity surface in contact with EP solution does not become out of the proper range, e.g., when the surface is above the liquid level, during draining and rinsing the acids, etc.
- Effectively remove hydrogen gas from the cavity and minimize the contact of the hydrogen gas with the cavity surface.
- Monitor and control the HF content precisely during EP
- Monitor and minimize the cell-to-cell temperature variation during EP

Table 3: Ongoing R&D's on EP at various institutions.

Institution	Topics
ANL	Low-beta cavities, anode/cathode geometries and orientations
Cornell	Vertical EP
DESY	Parameter validataion with 1-cell (with Henkel), components optimization with 9-cell cavities
FNAL	Papameter study with small samples
INFN/LNL, INFM/Naples U. Naples [30]	Automated EP
	Magnetometry for better cathode configuration
JLAB	Parameter validation, Continuous monitor and addition of HF
KEK/Nomura	Effect of CBP on the EP reproducibility
Saclay	Parameter validation, solution aging, method of surface qualification
U. Bruxelles	Analyses of EP phenomena
U. Wuppertal	Surface roughness measurement with Laser

COORDINATION OF EP R&D

While there are regional programs such as CARE that include EP studies, establishing a more global coordination is desirable to conduct more focused R&D in a timely manner. The following are suggestions that might expedite the R&D.

- Initiate the global R&D effort soon.
- Open a web page specialized on EP R&D
- Make an e-mailing list and circulate eNews as frequently as possible to disseminate new results for discussion and for a collection of useful data and references.

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[29] E. Palmieri, private communication.

[30] H. Padamsee, private communication.

APPENDIX A: DATA FROM K. SAITO'S PAPERS [1] AND [2]

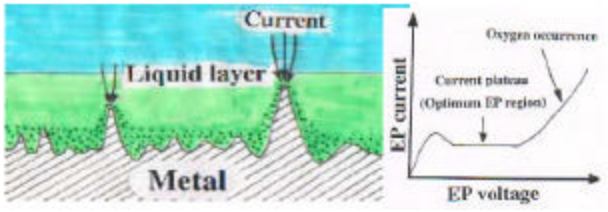

Figure A.1: Schematic representations of leveling effect by EP (left) and typical I/V curve during EP (right).

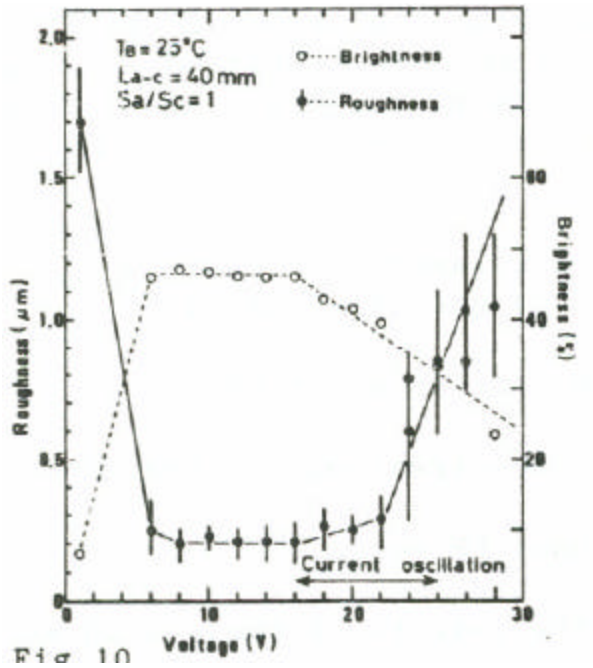

Figure A.2: Roughness and brightness as a function of voltage.

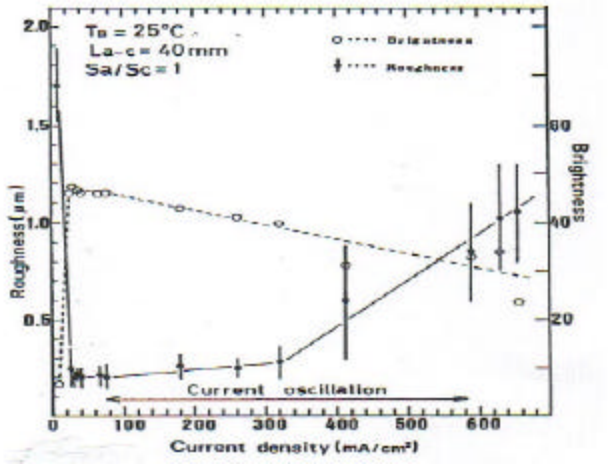

Figure A.3: Roughness and brightness as a function of current density.

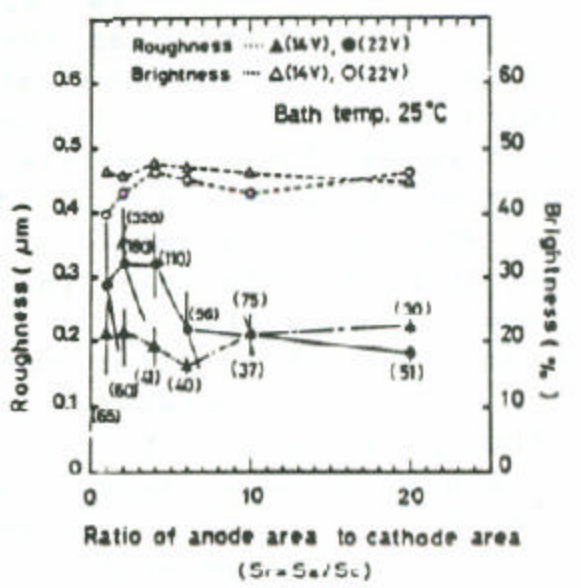

Figure A.4: Roughness and brightness as a function of ratio of anode to cathode surfaces.

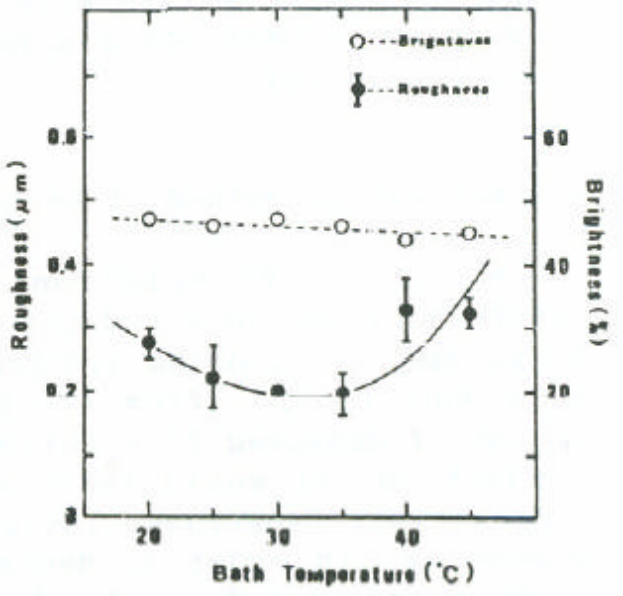

Figure A.5: Roughness and brightness as a function of bath temperature.

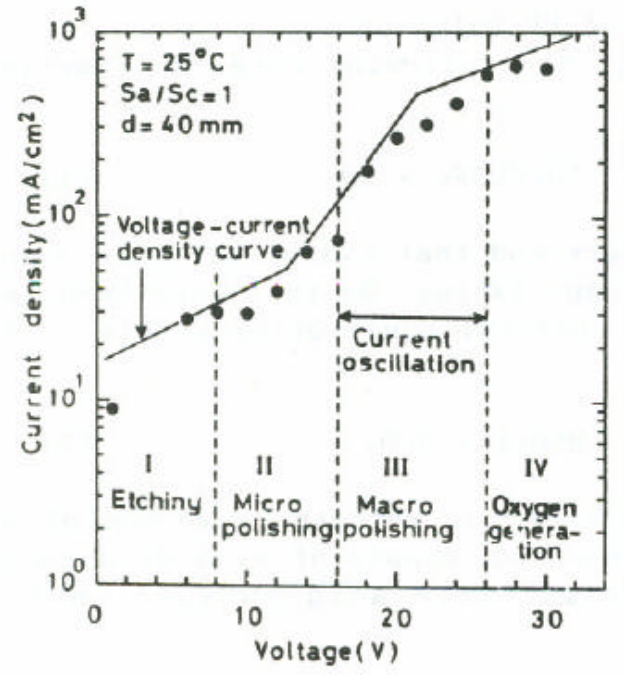

Figure A.6: Current density vs. voltage and various surface states resulting from these conditions.

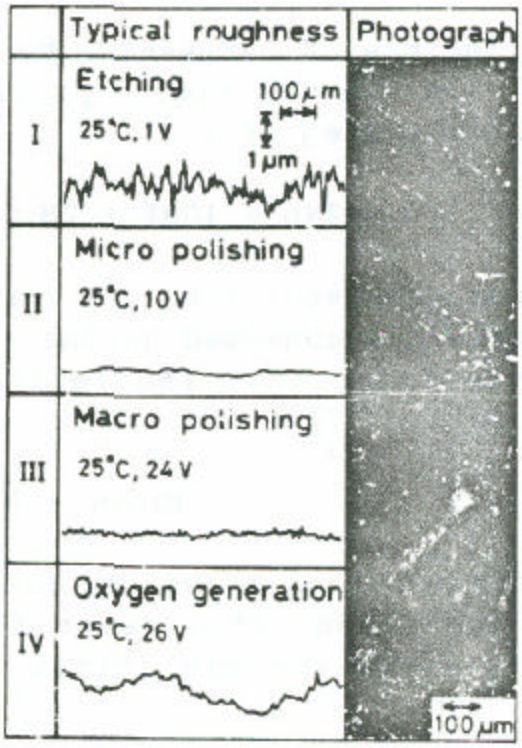

Figure A.7: Typical surface roughness and photograph for each polishing reason.

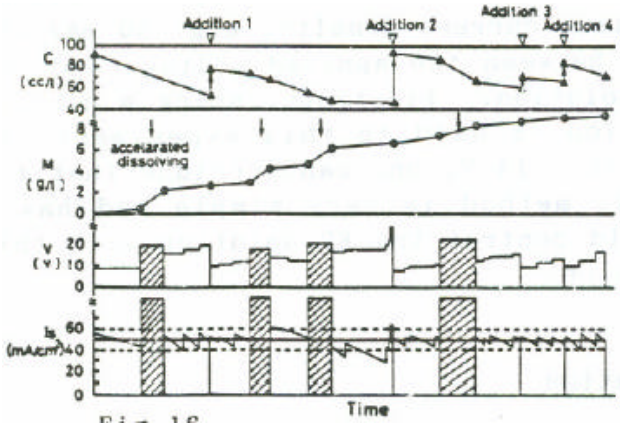

Figure A.8: Sample test on a refreshing method of an EP solution by the addition of $HS0_3F$.

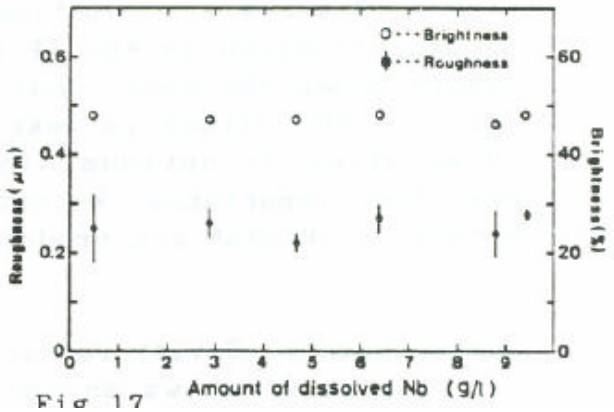

Figure A.9: Roughness and brightness as a function of the amount of dissolved Nb.

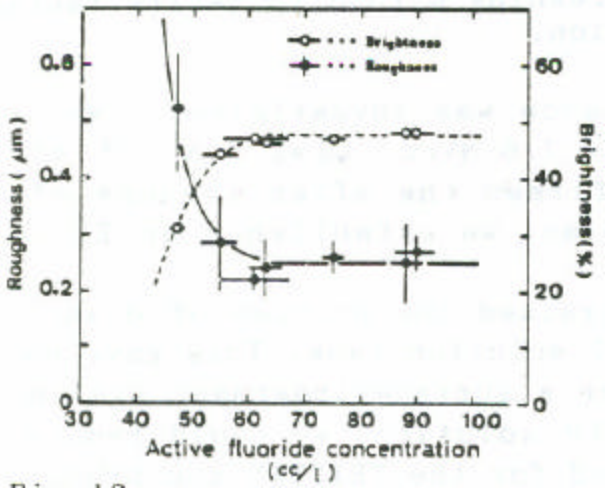

Figure A.10: Roughness and brightness as a function of HF concentration.

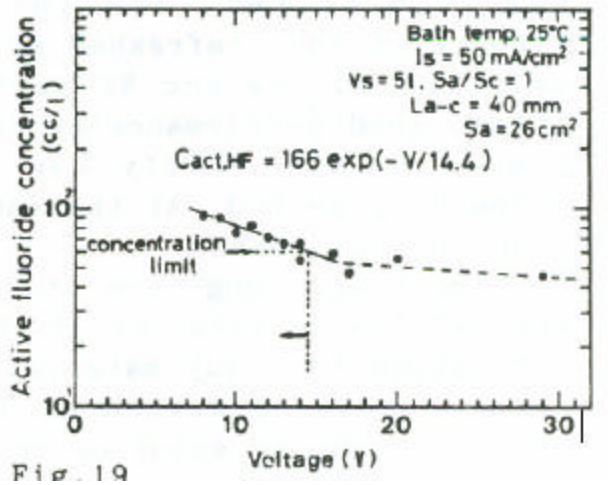

Figure A.11: HF content as a function of voltage to keep the current density at 50 mA/cm^2.

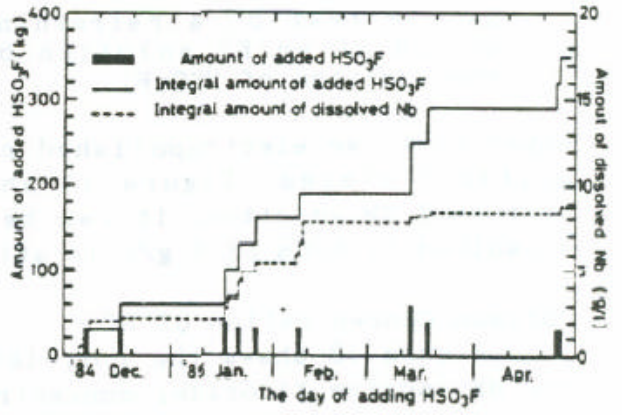

Figure A.12: Effect of adding HSO_3F on the amount of dissolved Nb.

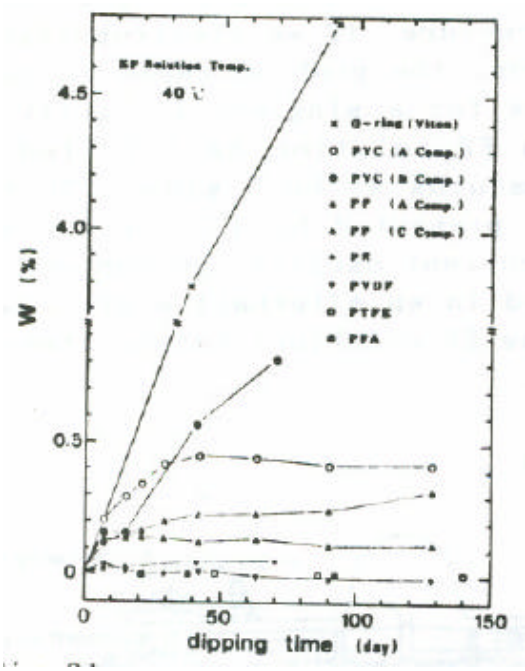

Figure A.13: Change of weight as an indication of absorption of EP solution for various materials.

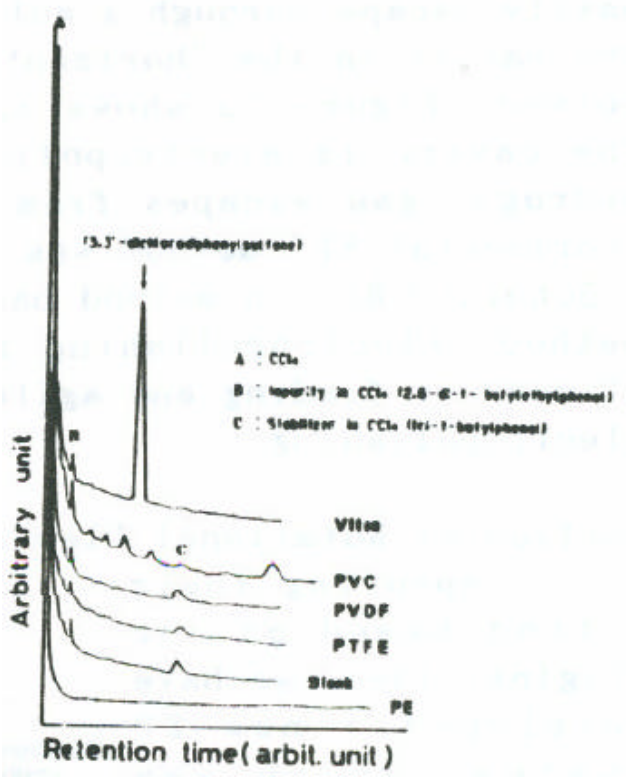

Figure A.14: Dissolving of plastic materials and Viton into an EP solution for two months soaking.

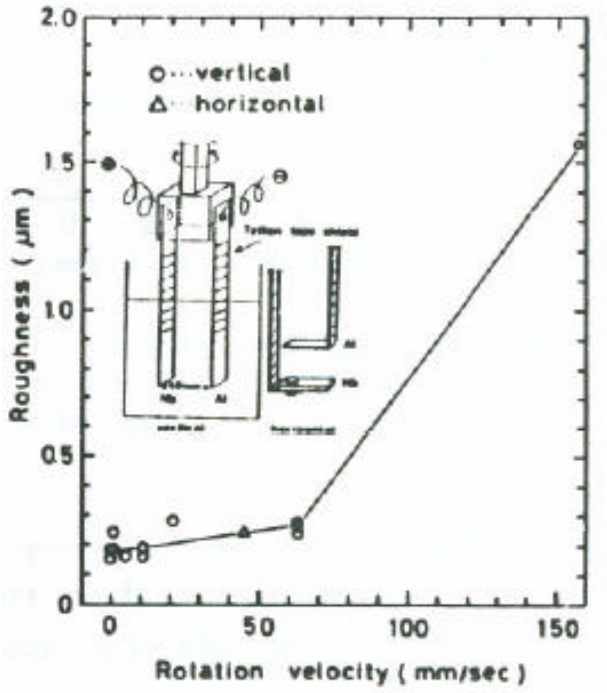

Figure A.15: Roughness as a function of the anode speed relative to the EP solution.

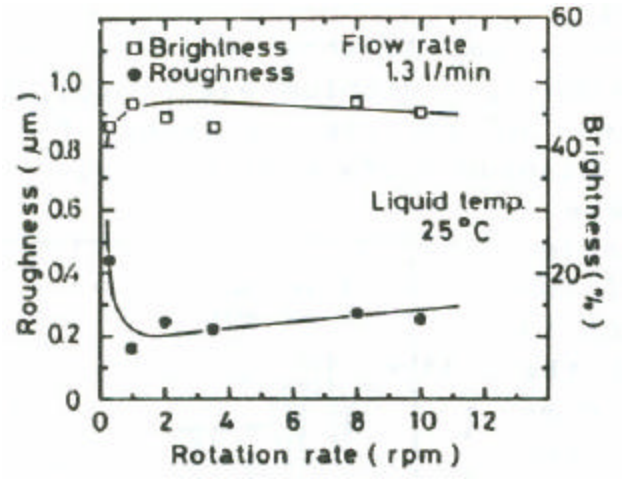

Figure A.16: Roughness and brightness as a function of cavity rotation speed. The cavity was a 1.5 GHz single cell.

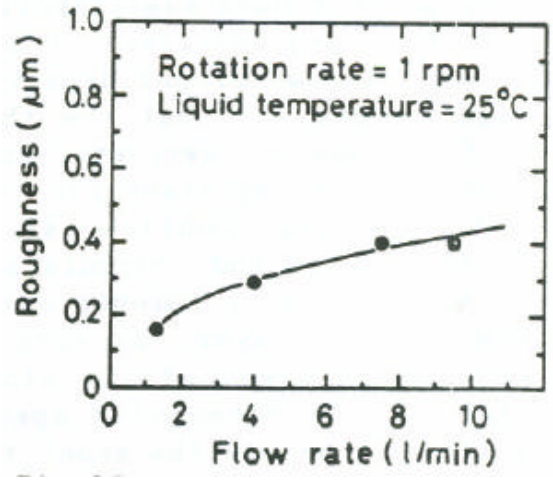

Figure A.17: Roughness vs. flow rate at a rotation speed of 1 rpm. One 1.5 GHz single-cell cavity was used.

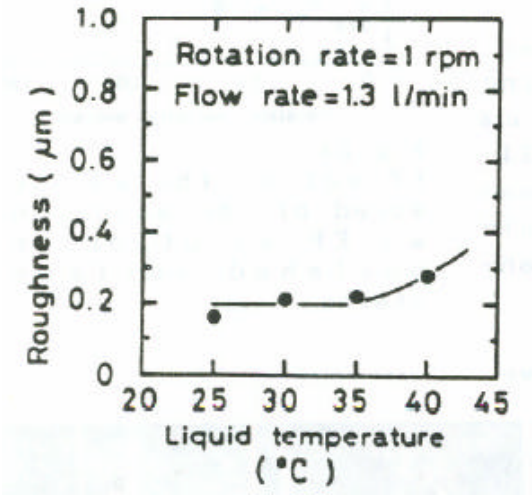

Figure A.18: Roughness as a function of EP solution temperature at a rotation 1 rpm and a flow rate of 1.3 l/min.

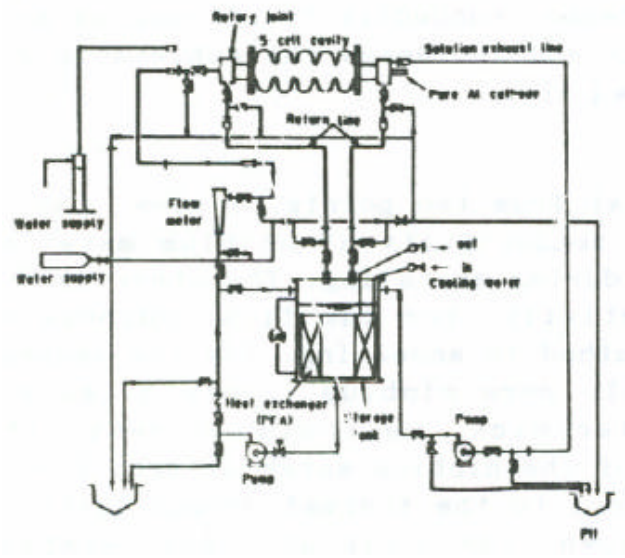

Figure A.19: Flow chart of the EP system for the TRISTAN 508 MHz 5-cell cavities.

APPENDIX B: CHEMICAL REACTIONS THAT OCCUR DURING EP

$$2Nb + 5SO_4^{--} + 5H_2O \rightarrow Nb_2O_5 + 10H^+ + 5SO_4^{--} + 10e^-$$
$$Nb_2O_5 + 6HF \rightarrow H_2NbOF_5 + NbO_2 \cdot 0.5H_2O + 1.5H_2O$$
$$NbO_2 \cdot 0.5H_2O + 4HF \rightarrow H_2NbF_5 + 1.5H_2O$$

(B.1) [25]

$$2Nb + 10HF + 2H_2O \Rightarrow 2H_2NbOF_5 + 5H_2 \quad \text{(B.2) [2]}$$
$$Nb_2O_5 + 10HF \Rightarrow 2H_2NbOF_5 + 3H_2O \quad \text{(B.3) [26]}$$

Cathode corrosion (Al) and Sulphur deposition

$$2Al + 4H_2SO_4 \rightarrow Al_2(SO_4)_3 + (S\downarrow) + 4H_2O$$

solution $\rightarrow$ alcohol rinse

(B.4) [26]

APPENDIX C: 9-CELL CAVITY EP SYSTEMS IN THE WORLD

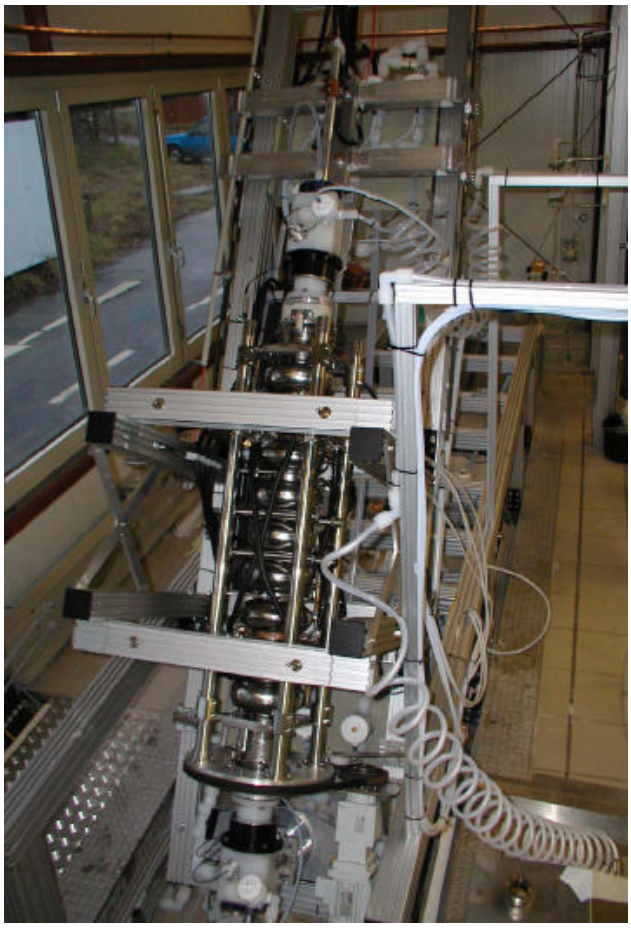

Figure C.1: DESY in Germany. [27]

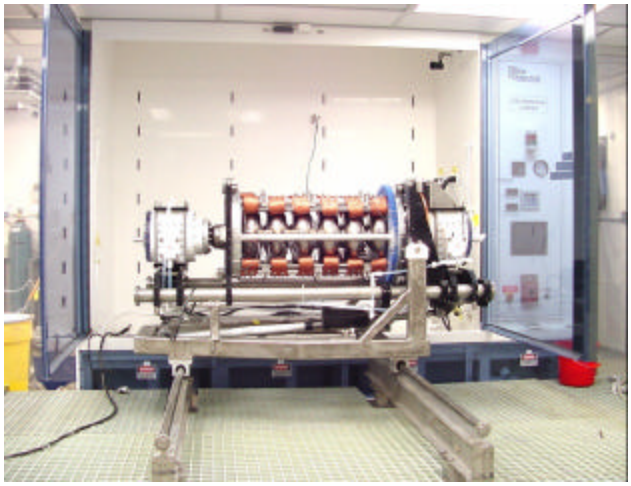

Figure C.2: JLAB in the U.S.A. [19]

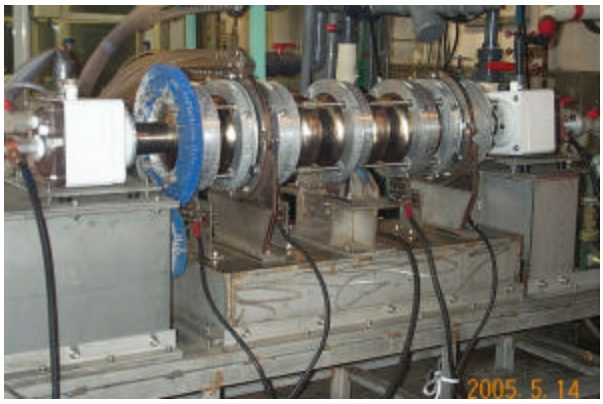

Figure C.3: KEK/Nomura in Japan. [28]

APPENDIX D: SINGLE-CELL AND SMALL AND OTHER EP SYSTEMS

Figure D.1: Henkel company in Germany. [27]

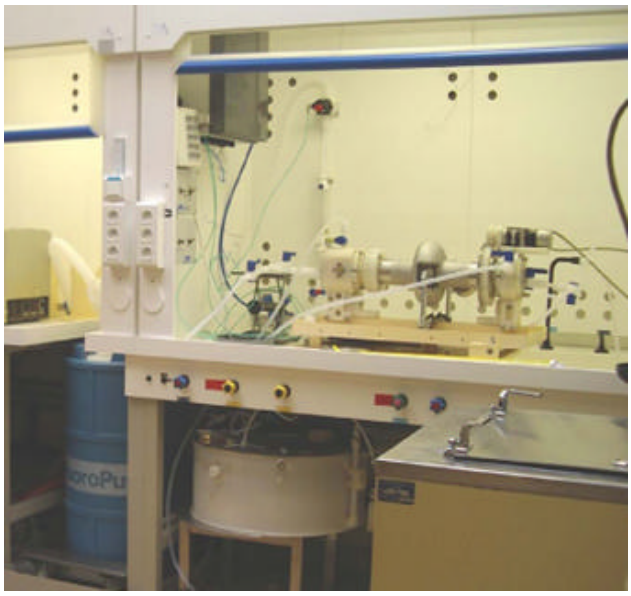

Figure D2: CEA/Saclay in France [20]. This system was transferred from CERN in 2003 [9].

Figure D.3: INFN/Legnaro in Italy [29]. They also can EP 3-cell cavities.

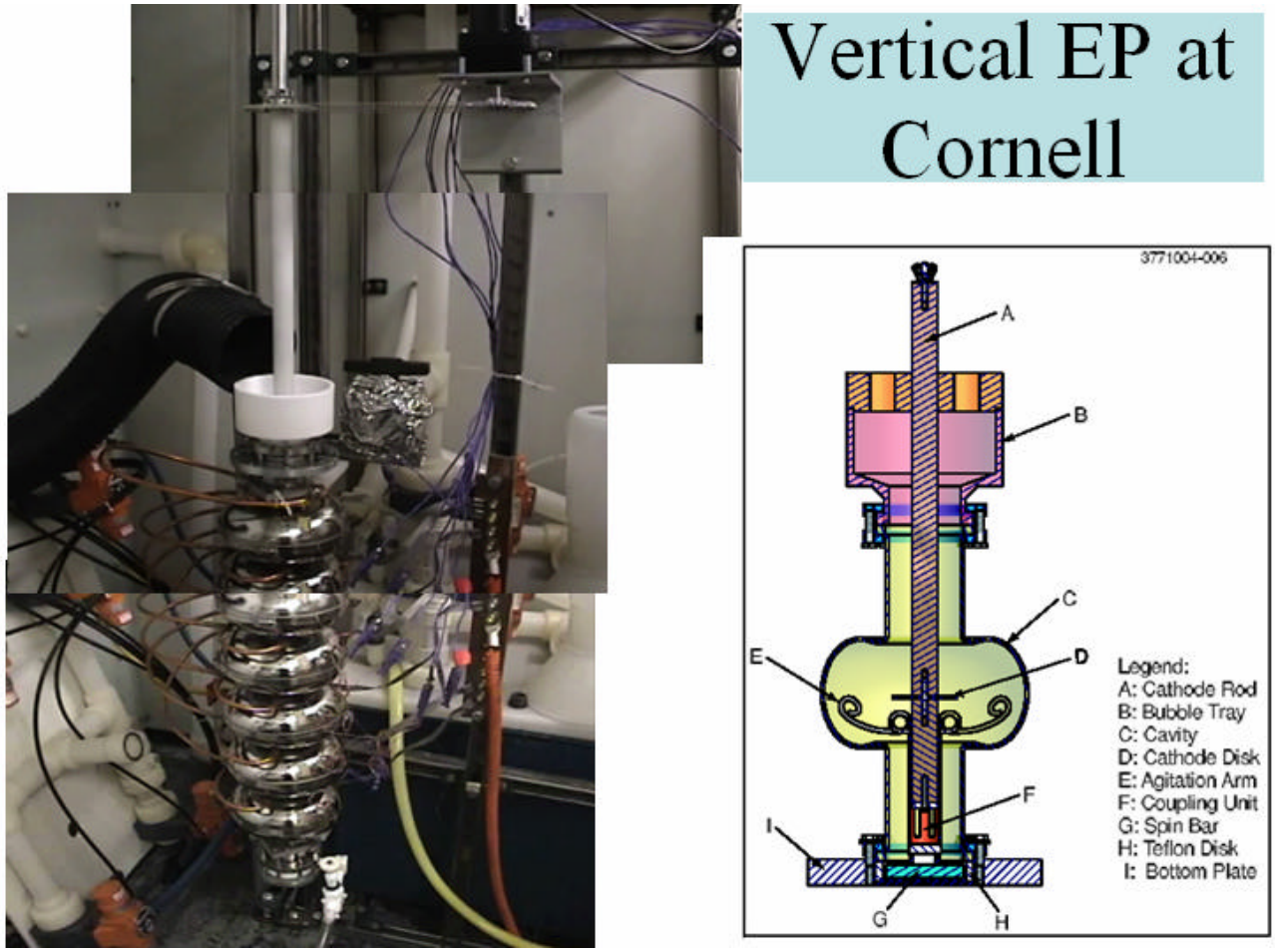

Figure D.4: Cornell vertical EP. The concept was proved with single cell cavities, e.g., a re-entrant cavity achieved 45 MV/m, and they are trying to apply it to multi-cell cavities as shown in the figure. [30]